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Abstract

This study compared effects of training at moderate, high, or a combination of the two intensities (mixed) on performance and physiological adaptations, when training durations were individualised. Untrained participants (n=34) were assigned to a moderate, high, or mixed group. Maximal oxygen uptake ($\dot{V}O_{2max}$), power output at $\dot{V}O_{2max}$ (MAP), time-to-exhaustion and gross efficiency were recorded before and after four weeks of cycling training (four times per week). The moderate group cycled at 60% MAP in blocks of 5 min with 1 min recovery, and training duration was individualised to 100% of pre-training time-to-exhaustion. The high group cycled at 100% MAP for 2 min with 3 min recovery, and training duration was set as the maximum number of repetitions completed in the first training session. The mixed group completed two moderate- and two high-intensity sessions each week, on alternate days. $\dot{V}O_{2max}$, MAP, and time-to-exhaustion increased after training ($P<0.05$), but were not different between groups ($P>0.05$). The mixed group improved their gross efficiency at 50% MAP more than the other two groups ($P = 0.044$) after training. When training is individualised for untrained participants, similar improvements in performance and physiological measures are found, despite marked differences in exercise intensity and total training duration.

Keywords: $\dot{V}O_{2max}$; time-to-exhaustion; training duration; cycling gross efficiency

Introduction

There is large inter-individual variability in adaptations to training, particularly when exercise is standardised to a percentage (%) of maximal oxygen uptake ($\dot{V}O_{2max}$) (Bouchard et al., 1999; Vollaard et al., 2009; McPhee, Williams, Dagens & Jones, 2010). Bouchard et al. (1999) were one of the first to highlight this variability after a standardised training intervention. The findings from this study demonstrated large variability in $\dot{V}O_{2max}$ adaptations, ranging from no change to ~42% increase after 10 weeks of training in sedentary individuals (Bouchard et al., 1999). Typically, these individual differences have been disregarded when setting training interventions (Gormley et al., 2008; Burgomaster et al, 2008). However, researchers have attempted to account for this by using individualised methods to prescribe training (Kiviniemi, Hautala, Kinnunen & Tulppo, 2007; Capostagno, Lambert & Lamberts, 2014). For example, Kiviniemi et al. (2007) monitored individual changes in daily resting heart-rate variability, and used this information to prescribe moderate- or high-intensity training sessions. An increase or no change in heart-rate variability recorded each morning before training resulted in a high-intensity session completed on that day, whereas, a decrease in heart-rate variability resulted in a moderate-intensity session (Kiviniemi et al., 2007). The findings from this study demonstrated that individualised training based on heart-rate variability produced greater improvements in maximal running speed, but not $\dot{V}O_{2peak}$, than those from a standardised training approach (Kiviniemi et al., 2007). Nevertheless, researchers have still reported large variability in training adaptations, despite tailoring the intensity of the sessions for each individual (Kiviniemi et al., 2007; Capostagno, Lambert & Lamberts, 2014).

To evaluate the effects of training intensity on performance and physiological adaptations, researchers frequently standardise the intensity of the training to a % of a maximum physiological characteristic (e.g. % heart rate max, %$\dot{V}O_{2max}$) (Helgerud et al., 2007; Gormley et al., 2008; Burgomaster et al., 2008). In addition, the duration of training is often fixed (Gormley et al., 2008). When standardised in this manner, high-intensity is often preferred to moderate-intensity training for greater or similar physiological and performance adaptations (Helgerud et al., 2007; Gormley et al., 2008; Burgomaster et al., 2008). But these results can vary depending on whether the total volume of training between intensity groups is matched. For example, Gormley et al. (2008) and Helgerud et al. (2007) reported greater increases in $\dot{V}O_{2max}$ with high-intensity, than from moderate-intensity training, when total volume and training frequency were matched. But when researchers have set the volume of moderate-intensity training ~90% higher than high-intensity training, groups did not differ (Gibala et al., 2006; Tanisho & Hirakawa, 2009; Burgomaster et al., 2008). It is common practice for cyclists to spend more time training at moderate- than high-intensity (Nimmerichter, Eston, Bachl, & Williams, 2011). For instance, a longitudinal study of trained cyclists identified training distributions of 73%, 22% and 5% for low-, moderate-, and high-intensity training respectively (Nimmerichter et al., 2011). Therefore, the greater increases in $\dot{V}O_{2max}$ reported in previous studies after high-intensity training might simply be because of insufficient volume of training prescribed to the moderate group (e.g. Helgerud et al., 2007; Gormley et al., 2008).

A notable observation is the large inter-individual variability in time-to-exhaustion performances (e.g. Coyle, Coggan, Hopper & Walters, 1988). Coyle et al. (1988) reported that the times cyclists could sustain exercise to exhaustion at 88% $\dot{V}O_{2max}$ were highly variable, ranging from 12-75 min. Thus, at the same relative intensity, individuals can tolerate exercise for different durations. The impact of this variability on subsequent training adaptations is not well understood, in particular when comparing effects of different training intensities. Therefore, this study examined the effects of four weeks of training at moderate-, high-, or a combination of the two (mixed) intensities, on performance and physiological responses, when training durations were individualised to each individual's maximum performance time. A four-week duration was chosen as previous research has reported large increases in $\dot{V}O_{2max}$ of up to 10% after 2-4 weeks of training (Rodas, Venturo, Cadefau, Cussó & Parra, 2000; Hautala et al., 2006; Laursen, Shing, Peake, Coombes & Jenkins, 2002). It was hypothesised that by maximising the duration of training for each individual there would be no differences among training intensities for performance and physiological adaptations.

Methods

Participants.

34 healthy men and women (25 and nine respectively) volunteered and completed this study (Table 1). All participants were untrained, and had engaged in no more than 3 h of exercise per week in the three months before the study. The study was approved by the University's ethics committee.

Study design.

Participants were randomly assigned to one of three training groups: moderate, high, or mixed and completed four weeks of supervised cycling training four times a week. Before and after the training programme, participants completed laboratory tests that assessed $\dot{V}O_{2max}$, power output at $\dot{V}O_{2max}$ (MAP), cycling gross efficiency, and time-to-exhaustion. The order of the testing procedures was as described below. All tests were performed on a stationary cycle ergometer (Lode Excalibur Sport, Lode, Grogningen, The Netherlands), which was set at hyperbolic mode. Participants were given at least 48 h between tests, except for the cycling gross efficiency and confirmation $\dot{V}O_{2max}$ test which were completed on the same day.

** Insert Table 1 near here **

Testing procedure.

$\dot{V}O_{2max}$: Ergometer seat and handlebar height were recorded for the same position to be used for all trials. The test started at 30 W, and increased by 20 W every min until volitional exhaustion, or the participant was no longer able to maintain the required intensity of exercise. The rates of oxygen uptake ($\dot{V}O_2$) and production of carbon dioxide ($\dot{V}CO_2$) were recorded

using the Douglas-bag method, as outlined by Hopker, Jobson, Gregson, Coleman and Passfield. (2012). Immediately before testing, the Douglas bags were emptied with a vacuum pump. Each participant was fitted with a Hans Rudolph breathing valve (2700; Hans Rudolph, Inc., Kansas City, MO), which was connected to the bags via a plastic tube. When a participant indicated that they were near exhaustion (e.g. at least 1 min of exercise remaining), gas collection was started (Hopker et al., 2012). Expired gas collection in the bags was timed to the nearest second. The O_2 and CO_2 concentrations of the expired air collected in the Douglas bags were analysed by an offline gas analyser (Servomex East Sussex, UK), which was calibrated using ambient air samples and a gas sample with known O_2 and CO_2 concentrations. A calibrated dry gas meter (Harvard Apparatus LtD, Edenbridge, UK) determined the expired volume of air in the bags and a digital thermometer (810-080 Electric Temperature Instruments, West Sussex, UK) determined the temperature of the gas sample in the Douglas bags. Each bag was analysed immediately after the test. The MAP was recorded as the 1 min mean cycling power output (W) attained during the incremental exercise test protocol to voluntary fatigue. Heart rate was recorded continuously using a wireless heart rate monitor. A single finger-prick blood sample was collected 1 min after testing and analysed for lactate concentration using a lactate analyser (Biosen C-line, EKF diagnostic, Barbleben, Germany).

Cycling gross efficiency: After a 10 min warm up at 50 W, participants cycled at two constant pre-determined intensities: 50 W for women or 75 W for men and 50% MAP. Participants were instructed to cycle for 7 min at each of the two intensities maintaining the same cadence. Expired air was collected into two Douglas bags during the last 2 min of each intensity, with a total of 1 min collected into each bag. Cycling gross efficiency was calculated as the ratio of external mechanical energy work done to energy input, expressed as a percentage (Passfield & Doust, 2000; Hopker et al., 2012). External mechanical energy work done was calculated from power output, and energy input from the energy equivalent of oxygen uptake and respiratory exchange ratio, assuming no contribution from protein (Péronnet and Massicotte, 1991). During collection of expired air participants were asked to maintain a normal breathing pattern, completing a ‘natural’ inhalation prior to opening and closing the Douglas bags. Participants were given a 5 s countdown before performing the inhalation phase (Hopker et al., 2012). The bags were opened at the start of the inspiration phase and closed also at the start of the inspiration phase to record a full pulmonary cycle. Ratings of perceived exertion (RPE) (Borg, 1970) and blood lactate were recorded at the end of each intensity.

Confirmation $\dot{V}O_{2max}$*:* Following the cycling gross efficiency test and 20 min passive recovery, participants completed a confirmation $\dot{V}O_{2max}$ test as described by Bouchard et al. (1999). The test started at 50 W for 5 min. Power output then increased to 50% MAP for 5 min, 70% MAP for 3 min and after this the intensity was increased to the MAP attained in the first $\dot{V}O_{2max}$ test for 2 min. If participants were able to continue after 2 min at MAP, the power output increased by 20 W every 2 min until volitional exhaustion occurred. Expired air was collected using Douglas bags as described previously. The mean $\dot{V}O_{2max}$ value attained from both tests was recorded as each participants $\dot{V}O_{2max}$, and if values differed by >5%, the higher $\dot{V}O_{2max}$ value was used (Bouchard et al., 1999). The reproducibility of MAP could not be examined in this study because of differences in test protocols and power output increments. As a result, MAP attained from the first $\dot{V}O_{2max}$ test before and after training was used in the analysis to compare effects of training.

Time-to-exhaustion: After a 5 min warm-up at 50 W participants cycled at 60% MAP for as long as possible until volitional exhaustion was reached. Participants were instructed to maintain a target cadence based on the mean cadence of their $\dot{V}O_{2max}$ test for as long as possible, and were provided with verbal encouragement. Exhaustion was determined when participants were unable to sustain the target power output or reached volitional exhaustion. Participants were not informed of the elapsed time, which was recorded to the nearest second. Blood lactate samples were recorded at 5 min and at the end of the test. RPE was recorded at 1 and 5 min.

Training: All training sessions were supervised in the laboratory and performed on a stationary cycle ergometer. The moderate group trained at 60% MAP for the duration completed in the pre-training time-to-exhaustion test. The moderate-intensity training session was divided into 5 min blocks separated by 1 min rest until the target training duration was reached. The high group completed 2 min repetitions at 100% MAP, followed by 2 min active rest at 25% MAP, and 1 min passive rest. Participants in the high group were instructed to complete as many repetitions as possible in their first training session, which set the baseline for subsequent training sessions. The mixed group completed two high-, and two moderate-intensity sessions each week, alternating between intensities for each session. Training progression was implemented for all three training groups by encouraging the participants to complete one extra repetition or 5 min block after every two training sessions. A halfway $\dot{V}O_{2max}$ test replaced one training session in week 3 and training power outputs were adjusted as necessary.

Statistical analysis.

A mixed-design factorial ANOVA examined the changes in physiological and performance parameters after four weeks of training. A Multivariate Analysis of Variance (MANOVA) examined the changes in physiological and performance parameters between groups, with sex and training group as factors. A Bonferroni *post-hoc* analysis was conducted when significant differences between groups were found. All data were checked for normality before conducting parametric analyses. Cohen's *d* effect sizes were calculated as the mean difference after training for physiological and performance parameters, divided by the pooled standard deviation (SD). Scores of 0.2, 0.5 and above 0.8 were considered small, moderate and large effect sizes respectively (Cohen, 1988; Cohen, 1992). Pearson's correlation examined relationships between % change (Δ) for: $\dot{V}O_{2max}$ or time-to-exhaustion and the other laboratory test measures (e.g. $\dot{V}O_{2max}$/time-to-exhaustion, MAP, cycling gross efficiency at 50% MAP and at 50/75 W). Statistical significance was set at $P < 0.05$. All values are reported as the mean (± SD).

To assess individual differences in training adaptations, the intra-individual coefficient of variation (CV) for laboratory test measures were identified from previous literature (Katch, Sady & Freedson, 1982; Scharhag-Rosenberger, Walitzek, Kindermann & Meyer, 2012; Wolpern, Burgos, Janot, & Dalleck, 2015). These measures included: $\dot{V}O_{2max}$ (CV = 5.6%) (Katch et al., 1982; Scharhag-Rosenberger et al., 2012; Wolpern et al., 2015), cycling gross efficiency (CV = 1.5%) (Hopker et al., 2012), and time-to-exhaustion (CV = 5.6%) (Maughan Fenn, & Leiper, 1989). The CV's for these measures were used to identify if participants were responders or non-responders to training, a method used previously by other researchers (Katch et al., 1982; Scharhag-Rosenberger et al., 2012; Wolpern et al., 2015). A non-responder was defined as one who demonstrated negative changes, or improved no greater than the CV of the laboratory test measure. A responder was one who demonstrated positive changes greater than the CV of the laboratory test measure. The above criteria are the same as those set by Scharhag-Rosenberger et al. (2012).

Results

The results for training-induced changes in men and women were compared for $\dot{V}O_{2max}$ (P = 0.590; d = 0.22), MAP (P = 0.639; d = 0.17), time-to-exhaustion (P = 0.613; d = 0.22), cycling gross efficiency at 50% MAP (P = 0.152; d = 0.51) and 50/75 W (P = 0.101; d = 0.74). There were no significant differences in training adaptations for men and women, although small to medium effects as indicated by Cohen's d. Therefore data was combined for men and women prior to subsequent analysis.

Training duration.

The mean total training time for the moderate, high, and mixed groups was ~16 h, 3 h and 8 h respectively. There was a large inter-individual variability in the durations each individual trained for at the three different intensities. The total training duration for each individual is presented in Figure 1.

** Insert Figure 1 near here **

Physiological and performance adaptations after training.

Significant changes in $\dot{V}O_{2max}$ (d = 0.29; 0.59; 0.29), MAP (d = 0.45; 0.63; 0.61), time-to-exhaustion (d = 1.18; 0.88; 1.00), cycling gross efficiency at 50/75 W (d = 0.21; 0.18; 0.87) and 50% MAP (d = 0.19; 0.12; 1.06) were found after four weeks of moderate-, high- and mixed-intensity training respectively ($P < 0.05$; Table 2). There were no differences among groups for changes in $\dot{V}O_{2max}$ ($P = 0.151$), MAP ($P = 0.983$), time-to-exhaustion ($P = 0.552$) or cycling gross efficiency at 50/75 W ($P = 0.375$). There was a significant difference between groups for changes in cycling gross efficiency at 50% MAP ($P = 0.044$) with the mixed group improving cycling gross efficiency at 50% MAP more so than the other two training groups (Figure 2). Cohen's *d* effect sizes for within and between group training adaptations are presented in Table 2 and Figure 3 respectively.

** Insert Figure 2 near here **

** Insert Table 2 near here **

** Insert Figure 3 near here **

Sub-maximal heart rate and blood lactate were lower after four weeks of training when recorded during the cycling gross efficiency test at 50/75 W and 50% MAP ($P < 0.05$). But these changes were not different among groups ($P > 0.05$). Sub-maximal VO_2 was significantly lower after training during cycling gross efficiency at 50/75 W and 50% MAP ($p < 0.05$) and these changes were significantly different between groups during the cycling gross efficiency test at 50% MAP ($P = 0.047$) but not during the cycling gross efficiency test at

50/75 W ($P > 0.05$). RPE was lower after training for cycling gross efficiency at 50% MAP ($P < 0.001$), but not cycling gross efficiency at 50/75 W ($P = 0.110$). But these changes were not different between groups ($P = 0.620$ and 0.862 for cycling gross efficiency at 50% MAP and 50/75 W respectively) (Table 3).

** Insert Table 3 near here **

Variability in training responses

Despite improvements in the mean physiological and performance measurements for all training groups, there was large inter-individual variability in adaptations (Table 4). For changes in $\dot{V}O_{2max}$, 54% (6/11), 83% (10/12) and 54% (6/11) of participants in the moderate, high, and mixed training groups respectively, had required changes after training, and were categorised responders. Alternatively, 46% (5/11), 17% (2/12), and 46% (5/11) of participants in the moderate, high, and mixed training groups respectively, did not have required changes in $\dot{V}O_{2max}$, and were categorised non-responders (Table 4).

** Insert Table 4 near here **

From Table 4, two participants in the moderate group (18%), five in the high group (42%), and five in the mixed group (46%), improved in all four measures. Each participant improved in at least one measure across all training groups. All participants improved performance after moderate and mixed training, with only one (8%) demonstrating a non-response to changes in performance from high-intensity training.

Correlations between physiological measurements and time-to-exhaustion

There was a weak correlation between the %Δtime-to-exhaustion and %Δcycling gross efficiency at 50% MAP ($r = 0.352$; $P = 0.041$; Figure 4). There was a moderate correlation between the %Δtime-to-exhaustion and %ΔMAP ($r = 0.503$; $P = 0.002$). There was no correlation between %Δtime-to-exhaustion and %Δcycling gross efficiency at 50/75 W (r = 0.210; P = 0.232), or %Δtime-to-exhaustion and %Δ$\dot{V}O_{2max}$ (r = 0.331; P = 0.056). There was no correlation between %Δ$\dot{V}O_{2max}$ and %Δcycling gross efficiency at 50% MAP (r = -0.171; P = 0.335) or at 50/75 W (r = -0.041; P = 0.818). There was a weak correlation between %Δ$\dot{V}O_{2max}$ and %ΔMAP (r = 0.344; P = 0.047).

** Insert Figure 4 near here **

Discussion

The main finding of this study was that four weeks of individualised training at either moderate-, high-, or mixed-intensity improved $\dot{V}O_{2max}$, MAP, time-to-exhaustion and cycling gross efficiency. However, there were no differences in changes among groups, except for cycling gross efficiency at 50% MAP, with the mixed-intensity training resulting in greater improvements than moderate- or high-intensity training alone. There was considerable heterogeneity in training responses for $\dot{V}O_{2max}$, cycling gross efficiency at 50/75 W and 50% MAP, despite individualising the training duration. Furthermore, all participants improved time-to-exhaustion after moderate-, and mixed-intensity training, with only one participant (8%) categorised as a non-responder after high-intensity training.

The similar physiological training adaptations in this study for all training intensities are consistent with those reported by Burgomaster et al. (2008) and Gibala et al. (2006). These studies fixed the duration of training, and did not account for the variability in durations individuals could sustain exercise at the same relative intensity (Coyle et al, 1988). The present study aimed to address this by tailoring the duration of training to each individual's maximum performance time. This resulted in a wide range of durations that participants trained for at the same relative intensity (Figure 1). The mean total time spent training was ~80% less for the high than the moderate group and ~63% less for the high than the mixed group. Therefore, despite a substantially greater time spent training at moderate-intensity, similar performance and physiological adaptations were observed among training intensities.

According to Laursen (2010), high-intensity and endurance training adaptations occur via two pathways: the adenosine monophosphate kinase pathway (AMPK) and the calcium-calmodulin kinase (CaMK) pathway. Laursen (2010) proposed that training at one exercise intensity will optimise the training adaptations that occur via only the pathway that predominates at that intensity. Therefore, for other adaptations to occur, an individual needs to be exposed to another exercise intensity (Laursen, 2010). This led researchers to investigate the physiological benefits of combining two training intensities (e.g. Neal, Hunter & Galloway, 2011; Munoz et al., 2014). The findings from the present study demonstrate that when two training intensities were combined (mixed group), increases in physiological and performance adaptations occurred. However, these training adaptations did not differ from those in the moderate-, and high-intensity training groups, except for cycling gross efficiency at 50% MAP. It is evident from Figure 2, that the mixed group improved cycling gross efficiency at 50% MAP more so than the other two training groups. It should also be noted that the moderate and high training groups had approximately equal changes in cycling gross efficieny at 50% MAP after training, despite a substantially longer time spent training at moderate-intensity.

The present study is one of few to take into account individual differences in performance capability when designing a training intervention (Kiviniemi et al., 2007, Capostagno et al., 2014). Despite attempts to tailor each individual’s training duration, large inter-individual variability in training responses were still apparent for all physiological adaptations, but not for performance adaptations. Responders and non-responders to training were determined using previously published intra-individual CV for physiological and performance laboratory test measurements. While there are some limitations to this method (e.g. it does not account for each individuals’ ‘actual’ day-to-day variability for the associated measure), we used the same method as that used by other researchers (Scharhag-Rosenberger et al. 2012; Wolpern et al., 2015). In our study, a responder was categorised as one who had positive changes greater than the CV of the laboratory test measure (Scharhag-Rosenberger et al., 2012). Whereas, a non-responder, was one who had negative changes, or improved no greater than the CV of the laboratory test measure (Scharhag-Rosenberger et al., 2012). Examination of the individual responses presented in Table 4 indicates that a non-responder for one measure was not necessarily a non-responder for other variables. This is similar to the findings of Vollaard et al. (2009) following a six week standardised training intervention. In addition, Table 4 indicates that all participants improved in at least one physiological and performance measurement. The mixed group had most responders (46%) in all laboratory test measures, followed by the high (42%) and moderate (18%) training groups. Additionally, the high group had most responders for $\dot{V}O_{2max}$ changes (83%), followed by the mixed (54%) and moderate (54%) training groups. This supports previous research that the inclusion of high-intensity sessions in a training intervention can induce slightly greater improvements in $\dot{V}O_{2max}$ (Bacon, Carter, Ogle & Joyner, 2013). It should also be noted that in our sample of 34 participants, only one had a negative change for time-to-exhaustion after training. This participant was in the high group. This finding warrants further investigation. It could be that by repeatedly exposing participants to their maximum duration of exercise in training, their ability to tolerate exercise to exhaustion increases. In particular, this could be the case for the moderate and high training groups who trained at the intensity set for the time-to-exhaustion test (60% MAP).

There was a relationship between time-to-exhaustion performances and cycling gross efficiency at 50% MAP before and after training. Furthermore, the training adaptations for time-to-exhaustion and cycling gross efficiency were also positively correlated, with ~12% of the improvements in time-to-exhaustion after training related to changes in cycling gross efficiency at 50% MAP. Previous research has demonstrated that a high cycling gross efficiency is associated with a higher power output sustained during a 1 h cycling time-trial (Horowitz, Sidossis & Coyle, 1994). In addition, others have reported differences between trained and untrained individuals for cycling gross efficiency, as well as changes in cycling gross efficiency over the course of a competitive training season (Hopker, Coleman, Passfield & Wiles, 2010). However, the correlation between the %Δcycling gross efficiency and the %Δtime-to-exhaustion performance following a training intervention has not been examined previously. Figure 4 shows that individuals who had the greatest increases in cycling gross efficiency after training, also had the greatest improvements in time-to-exhaustion performance.

There was also a positive relationship between %Δtime-to-exhaustion and %ΔMAP, but there was no relationship between %Δtime-to-exhaustion and %Δ$\dot{V}O_{2max}$. Our findings are consistent with Vollaard et al. (2009) who reported no relationship between the training-induced %Δ$\dot{V}O_{2max}$ and the %Δtime-trial performance after a standardised training intervention. Vollaard et al. (2009) concluded that the aerobic capacity and aerobic performance adaptations do not occur in proportion to each other, and therefore there is a poor link between these two measures. More research is needed to improve our understanding of the relationship between physiological measures and time-to-exhaustion or time-trial performances both in trained and untrained individuals. It should also be noted that in bivariate analysis, coefficients can be influenced more by the range in one or both variables than the inherent relationship between the two (Sale, 1991).

In conclusion, similar improvements occurred in $\dot{V}O_{2max}$, MAP, cycling gross efficiency and time-to-exhaustion despite substantially greater durations spent training at moderate- compared to high- or mixed-intensity, in untrained participants. These findings support the contention that individualised training at high or mixed intensities are a more effective use of time in training. In addition, mixed-intensity training provided the greatest benefit to cycling gross efficiency at 50% MAP and resulted in more responders to training than in the moderate and high-intensity training groups. The untrained status of the participants recruited in this study is a limiting factor. Future research should aim to also study the effects of individualised training durations at different intensities in trained and elite-standard athletes.

Acknowledgements: The authors thank the participants for their participation.

Table 1: Mean (±SD): Age, body mass, $\dot{V}O_{2max}$, and MAP for moderate, high and mixed groups after training.

	Moderate (*n* = 11)	**High** (*n* = 12)	**Mixed** (*n* = 11)
Age (yrs.)	31 ± 12	28 ± 9	26 ± 5
Body Mass (kg)	76.4 ± 13.4	73.9 ± 11.2	77.2 ± 13.2
$\dot{V}O_{2max}$ (L.min^{-1})	3.4 ± 0.8	3.1 ± 0.6	3.7 ± 0.7
MAP (W)	241 ± 55	232 ± 42	259 ± 50

Table 2: Physiological and performance measures before and after four weeks of moderate, high and mixed-intensity training. Change scores (Δ) and Cohen's *d* effect sizes for within group training adaptations are also presented. * Significant change after training. *P* < 0.05.

	Group	Pre	Post	Δ	Cohen's *d*
$\dot{V}O_{2max}$ (L.min^{-1})	Moderate	3.35 ± 0.78	3.58 ± 0.77 *	0.23 ± 0.18	0.29
	High	3.10 ± 0.59	3.46 ± 0.65 *	0.37 ± 0.19	0.59
	Mixed	3.72 ± 0.67	3.93 ± 0.80 *	0.21 ± 0.35	0.29
MAP (W)	Moderate	241 ± 55	266 ± 53 *	24 ± 18	0.45
	High	232 ± 42	261 ± 49 *	29 ± 14	0.63
	Mixed	259 ± 50	290 ± 52 *	31 ± 17	0.61
Time-to-exhaustion (s)	Moderate	2943 ± 1128	4496 ± 1507 *	1553 ± 722	1.18
	High	2641 ± 1382	3898 ± 1483 *	1257 ± 677	0.88
	Mixed	2725 ± 1098	4060 ± 1573 *	1335 ± 688	1.00
Cycling gross efficiency at 50/75 W (%)	Moderate	12.85 ± 1.41	13.17 ± 1.64 *	0.32 ± 1.11	0.21
	High	13.05 ± 1.67	13.33 ± 1.36 *	0.28 ± 1.22	0.18
	Mixed	12.09 ± 1.14	13.15 ± 1.32 *	1.06 ± 1.17	0.87
Cycling gross efficiency at 50% MAP (%)	Moderate	16.05 ± 1.28	16.28 ± 1.16 *	0.23 ± 1.04	0.19
	High	16.15 ± 1.39	16.00 ± 1.01 *	0.15 ± 1.06	0.12
	Mixed	15.86 ± 0.89	16.95 ± 1.18 *	1.09 ± 0.93	1.06

Table 3: Submaximal physiological and perceptual responses before and after four weeks of moderate, high and mixed training. * Significant change after training. $P < 0.05$.

		Moderate	High	Mixed
Cycling gross efficiency at 50% MAP				
Lactate ($mmol.L^{-1}$)	Pre	4.30 ± 1.57	4.15 ± 1.10	3.28 ± 0.74
	Post	2.00 ± 0.77 *	2.70 ± 0.94 *	2.01 ± 0.86 *
Heart rate (bpm)	Pre	138 ± 17	142 ± 18	142 ± 12
	Post	128 ± 15 *	132 ± 15 *	130 ± 16 *
RPE (6-20)	Pre	13 ± 2	13 ± 2	13 ± 1
	Post	11 ± 1 *	11 ± 2 *	11 ± 1 *
$\dot{V}O_2$ ($L.min^{-1}$)	Pre	2.11 ± 0.42	2.03 ± 0.32	2.27 ± 0.36
	Post	2.09 ± 0.41 *	2.04 ± 0.28 *	2.13 ± 0.32 *
Cycling gross efficiency at 50/75 W				
Lactate ($mmol.L^{-1}$)	Pre	2.41 ± 1.24	2.13 ± 0.88	1.73 ± 0.60
	Post	1.38 ± 0.38 *	1.56 ± 0.53 *	1.25 ± 0.38 *
Heart rate (bpm)	Pre	116 ± 19	121 ± 15	117 ± 6
	Post	111 ± 17 *	113 ± 14 *	107 ± 10 *
RPE (6-20)	Pre	10 ± 2	10 ± 2	10 ± 1
	Post	10 ± 1	9 ± 2	10 ± 1
$\dot{V}O_2$ ($L.min^{-1}$)	Pre	1.50 ± 0.25	1.49 ± 0.25	1.59 ± 0.25
	Post	1.47 ± 0.26 *	1.45 ± 0.16 *	1.46 ± 0.17 *

Table 4. Individual responders and non-responders for changes in $\dot{V}O_{2max}$, time-to-exhaustion, cycling gross efficiency at 50/75 W and 50% MAP following four weeks of training (n = 34). Black = non-responder, white = responder, when CV's of $\dot{V}O_{2max}$, time-to-exhaustion, cycling gross efficiency are subtracted from the percentage change (%Δ) for each individual (n = 34).

Moderate

Participant no.	1	2	3	4	5	6	7	8	9	10	11	∑
$\dot{V}O_{2max}$ ($L.min^{-1}$)		■			■	■	■	■				n=5 (46%)
Time-to-exhaustion (s)												n=0 (0%)
Cycling gross efficiency at 50/75 W (%)	■	■	■						■			n=4 (36%)
Cycling gross efficiency at 50% MAP (%)		■	■	■	■							n=4 (36%)

High

Participant no.	1	2	3	4	5	6	7	8	9	10	11	12	∑
$\dot{V}O_{2max}$ ($L.min^{-1}$)		■					■						n=2 (17%)
Time-to-exhaustion (s)					■								n=1 (8%)
Cycling gross efficiency at 50/75 W (%)		■			■	■		■		■			n=5 (42%)
Cycling gross efficiency at 50% MAP (%)			■		■	■	■	■		■			n=6 (50%)

Mixed

Participant no.	1	2	3	4	5	6	7	8	9	10	11	∑
$\dot{V}O_{2max}$ ($L.min^{-1}$)	■						■		■	■	■	n=5 (46%)
Time-to-exhaustion (s)												n=0 (0%)
Cycling gross efficiency at 50/75 W (%)					■				■			n=2 (18%)
Cycling gross efficiency at 50% MAP (%)									■	■		n=2 (18%)

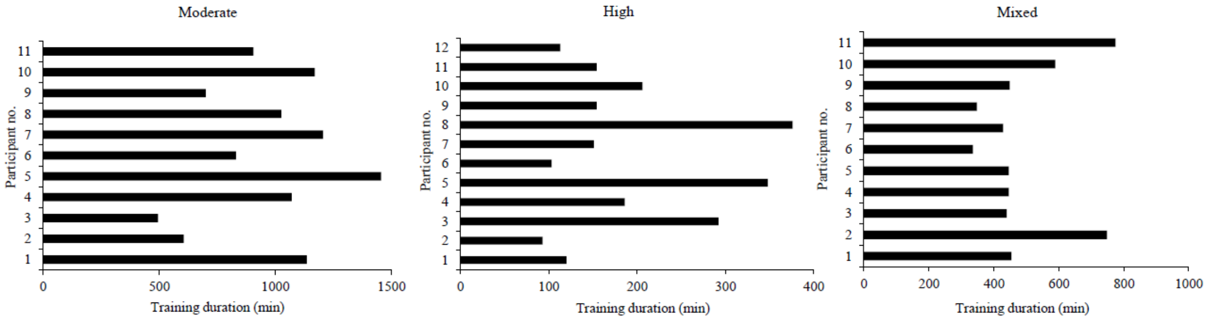

Figure 1: Total duration of training for each individual after 4 weeks of moderate, high or mixed-training.

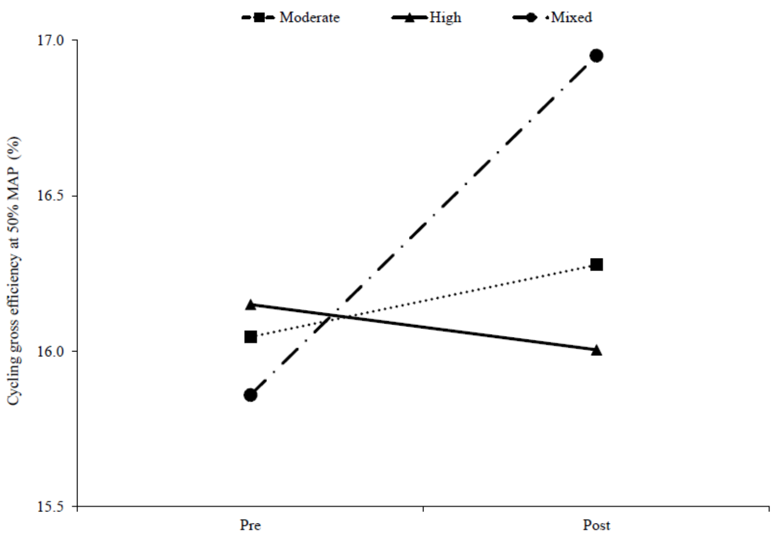

Figure 2: A significant difference between groups for cycling gross efficiency at 50% MAP following training, with the mixed group improving cycling gross efficiency at 50% MAP more so than the other two training groups (P<0.05).

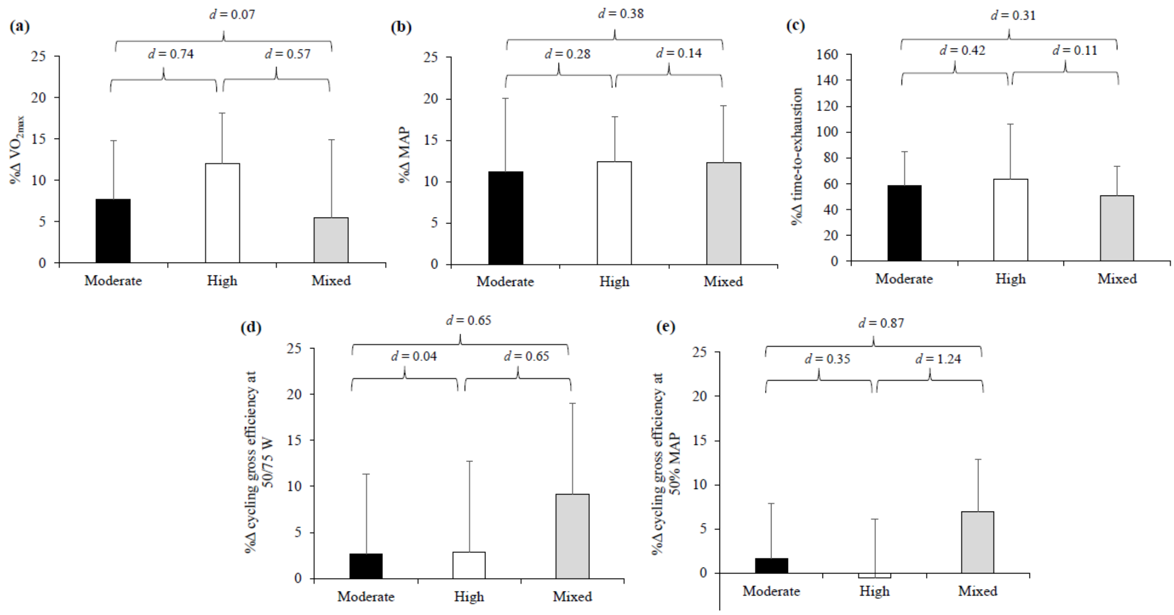

Figure 3: Mean (±SD): Percentage change (%Δ) in physiological and performance measures following 4 weeks of moderate, high or mixed training. Cohen's *d* effect sizes for between group training adaptations are also presented. a: $\dot{V}O_{2max}$; b: MAP; c: time-to-exhaustion; d: cycling gross efficiency at 50/75 W; e: cycling gross efficiency at 50% MAP.

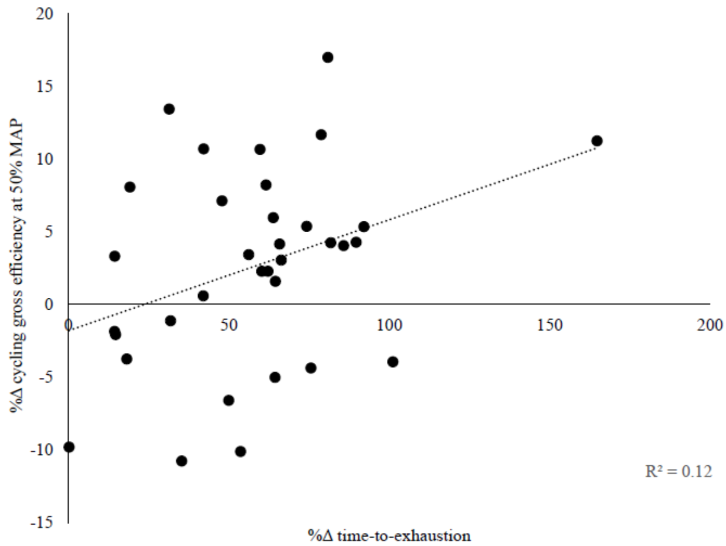

Figure 4: A weak relationship between percentage change (%Δ) in cycling gross efficiency at 50% MAP and time-to-exhaustion (*P*<0.05).

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